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IN SITU GAS PERMEABILITY TESTING IN THE NO. 2 AND NO. 3 TUNNELS, DONKIN-MORIEN PROJECT, NOVA SCOTIA

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IN SITU GAS PERMEABILITY TESTING IN THE NO. 2 AND
NO. 3 TUNNELS, DONKIN-MORIEN PROJECT, NOVA SCOTIA

by

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ABSTRACT

In situ nitrogen permeability testing was undertaken in a borehole drilled between the No. 2 and No. 3 Tunnels at the Donkin-Morien Project. The object of this work was to assess whether the technique of in situ gas permeability testing could be used to assess changes in the sidewall rock integrity caused by the different excavation methods used to drive the two tunnels. After a description of the test site, equipment and procedures, the results are presented and discussed.

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VÉRIFICATION IN SITU DE LA PERMÉABILITÉ DES GAZ DANS LES
TUNNELS N^{OS} 2 et 3 AU PROJET DONKIN-MORIEN EN NOUVELLE-ÉCOSSE

par

W.D. Gallant*, D.M. Hamilton** et T.R.C. Aston*

RÉSUMÉ

La vérification in situ de la perméabilité de l'azote a été effectuée à partir d'un trou de sonde creusé entre les tunnels n^{OS} 2 et 3 au projet Donkin-Morien. Le but des travaux était de déterminer si la technique de vérification in situ de la perméabilité des gaz pouvait être utilisée pour évaluer les changements qui se produisent au niveau de l'intégrité de la paroi rocheuse latérale et qui résultent des diverses méthodes d'excavation qui ont été utilisées pour percer les deux tunnels. L'auteur donne une description du chantier où la vérification a été effectuée et présente les résultats qui font l'objet d'une discussion.

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CONTENTS

	<u>Page</u>
ABSTRACT	1
RESUME	11
NOMENCLATURE	iv
INTRODUCTION	1
TEST SITE AND GEOLOGY	2
TEST EQUIPMENT AND PROCEDURES	2
THEORETICAL DETERMINATION OF PERMEABILITY	5
EXAMPLE CALCULATION	6
TEST RESULTS	9
DISCUSSION OF RESULTS	11
CONCLUSIONS	11
REFERENCES	13
APPENDIX A	14
APPENDIX B	21

TABLES

<u>No.</u>	<u>Page</u>
1. Calculation of flow rates and permeabilities, borehole Ch 804 m, Donkin-Morien Project	10

FIGURES

<u>No.</u>	<u>Page</u>
1. Packer arrangement within the borehole	3
2. Gas supply and control circuit for test section	4
3. Pressure decay curve, No. 3 Tunnel test section at 3 ft	8
4. Nitrogen in situ strata permeability against distance of test section from tunnel sidewall	12

NOMENCLATURE

Q_s - ft^3/day at 60°F and 1 atm
 k - permeability (darcies)
 k_a - permeability for air
 k_n - permeability for nitrogen
 h - width of aquifer (ft)
 μ_a - viscosity of air (cp)
 μ_n - viscosity of nitrogen (cp)
 P_e - pressure in reservoir (psi)
 P_w - pressure between packers (psi)
 r_e - radius at which reservoir conditions exist (ft)
 r_w - radius of borehole (ft)
 T_f - absolute flowing temperature ($^\circ\text{R} = ^\circ\text{F} + 460^\circ$)
 q - gas flow rate at 60°F and 1 atm
 V - volume of gas in the system
 H_1 - initial pressure in cavity (cm Hg)
 H_2 - final pressure in cavity (cm Hg)
 Δt - time
 d_c - diameter of test section (cms)
 d_T - internal diameter of tubing (cms)
 h - length of test section (cms)
 L - length of tubing (cms)

NOTE: The radial gas flow and associated equations given by Herget (4) and Calhoun (5) were all derived for use with imperial units. All metric data obtained during this exercise was therefore converted to imperial units in order to simplify the use of these equations.

INTRODUCTION

In the late 1970's the Cape Breton Development Corporation (CBDC) identified a major offshore coal resource block off Cape Perce, Cape Breton Island. After a comprehensive definition study, site work on the Donkin-Morien Development Project began in 1980. Originally, the project called for four cross-measure access tunnels with a total length of 15.6 km. The initial phase of the Donkin-Morien project called for the development of two tunnels (Nos. 2 and 3), each 3.5 km in length, to intersect the Harbour Seam.

A 7.6 m diameter full face tunnel boring machine was used to drive the No. 2 Tunnel a distance of 3522 m, between October 1983 and December 1984. The No. 3 Tunnel, a uniradial arch 7.6 m wide by 5.3 m high was advanced a total distance of 1027 m using drill and blast methods, between January 1982 and February 1983. At present, January 1986, the TBM is being reassembled in the No. 3 Tunnel in order to drive the remaining 2500 m, which is expected to be completed by September 1986. The distance between the No. 2 and No. 3 Tunnel centre lines is 50 m.

During the No. 2 Tunnel driveage a major geotechnical research project was undertaken to monitor and compare the rock/support interaction of the TBM and Drill and Blast tunnels (1). One aspect of this project involved a program of in situ strata modulus testing in order to compare the effects of the two different excavation methods. The in situ strata modulus testing was undertaken by Ontario Hydro using the Colorado School of Mines dilatometer system.

To augment the dilatometer data, a series of in situ gas permeability tests were undertaken in a borehole drilled between the No. 2 and No. 3 Tunnels. This work was undertaken to assess whether the in situ gas permeability technique could be used as a simple method of assessing changes in the in situ rock integrity due to the use of different excavation methods.

This report undertakes a description of the site, test equipment and procedures used as well as a discussion of the results obtained.

TEST SITE AND GEOLOGY

The nitrogen permeability testing was conducted in a borehole located at chainage 804 m, which was drilled through from the No. 3 to the No. 2 Tunnel.

Geologically, the borehole is located in a massive fine to medium grained sandstone containing intermittent clay, siltstone and coarse sandstone laminations. Geotechnically, the sandstone varies in uniaxial compressive strength from 68 to 140 MPa with a mean value of 98 MPa (2).

TEST EQUIPMENT AND PROCEDURES

To facilitate in situ permeability testing, a section of the borehole was sealed off using a double inflatable packer arrangement. A known gas pressure was then introduced to the test section, the test section sealed and the resultant pressure decay monitored. The gas loss/pressure decay can be ascribed to one of two mechanisms:

- 1) gas migration through the porous/permeable sandstone strata.
- 2) gas migration along either natural or induced fracture/discontinuity networks.

The test equipment consisted of a Model VLP 40/60 packer system obtained from Rocrest of Montreal and designed to fit a 75 mm diameter borehole. The packer consisted of two inflatable rubber glands 1 m long separated by an 0.5 m section of perforated steel tubing, Figure 1. Transmission lines connecting the packer with the gas supply and control circuit, consisted of thick walled nylon tubes 2 mm ID and 6 mm OD, Figure 2.

For underground use, the packers were inflated with hydraulic fluid using an Enerpac Jack. To reduce test time, the packers were inflated to 70 mm diameter prior to transportation underground.

Each test involved locating the packer test section, a known distance from the borehole collar. Once located, the packers were inflated and the test section pressurized with nitrogen gas from a 'Portaflam' cylinder to a value of approximately 30 psi (0.21 MPa). The gas supply was

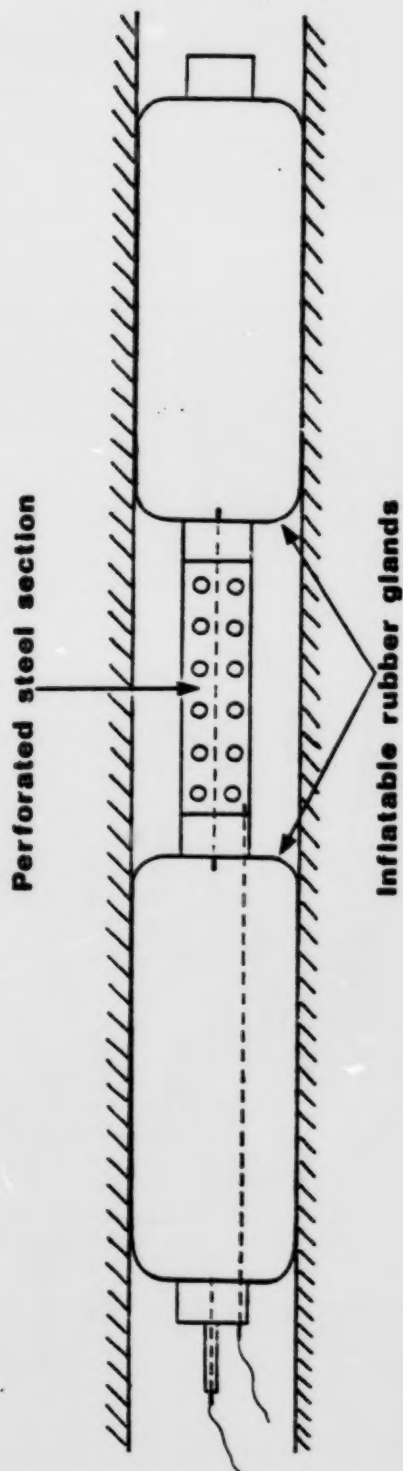


Figure 1 - Packer arrangement within the borehole

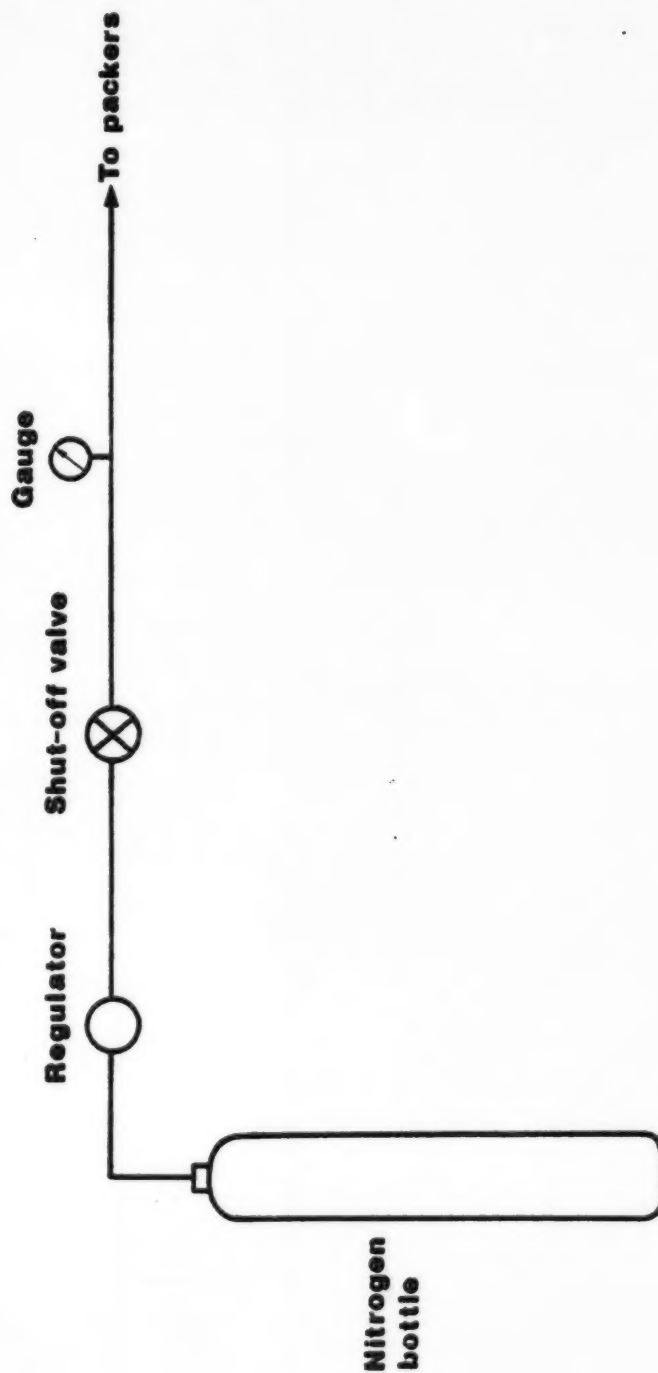


Figure 2 - Gas supply and control circuit for test section .

then switched off and the test section pressure decay monitored against time. This procedure was repeated at different intervals along the borehole from both the No. 2 and No. 3 Tunnel side walls. Low gas pressures were used in the test section to prevent induced fracturing of the borehole wall.

A similar test arrangement was used to determine in situ strata pressure at No. 26 Colliery (3).

THEORETICAL DETERMINATION OF PERMEABILITY

In 1981, a series of in situ gas permeability determinations were undertaken in a West German potash mine by CANMET personnel (4). In this report (4), an equation is given for the determination of radial gas flow surrounding a borehole (5):

$$Q_s = \frac{10320 \text{ kh} (P_e^2 - P_w^2)}{\mu \ln(r_e/r_w) T_f (14.65)} \quad \text{Eq 1}$$

The flow rate can be calculated from volume changes by measuring the pressure drop in the cavity using equation 2:

$$q = V \frac{520^\circ\text{R}}{515^\circ\text{R}} \cdot \frac{H_1 - H_2}{76 \Delta t} \quad \text{Eq 2}$$

where, V = Cavity volume + volume of tubing

$$V = \frac{\pi d_c^2}{4} h + \frac{\pi d_T^2}{4} L \quad \text{Eq 3}$$

Equation 1 requires that the flow rate be expressed in cubic feet per day:

$$Q_s = \frac{q}{19.66} \quad \text{Eq 4}$$

Once Q_s is determined, the permeability can be calculated by rearranging equation 1:

$$k = \frac{\mu \ln(r_e/r_w) T_f (14.65) Q_s}{10320 h (P_e^2 - P_w^2)} \quad \text{Eq 5}$$

If the following values representative of the Donkin-Morien conditions are substituted into equations 1, 2 and 3:

$$\begin{aligned} h &= 1 \text{ m (3.28 ft)} \\ \mu &= 0.0185 \text{ cp (air) or} \\ &\quad 0.0173 \text{ cp (nitrogen)} \\ P_e &= 15 \text{ psi} \\ r_e &= 10 \text{ ft} \\ r_w &= 0.123 \text{ ft (37.5 mm)} \\ T_f &= 515 \text{ }^\circ\text{F (55}^\circ + 460^\circ) \\ d_e &= 7.5 \text{ cm} \\ d_T &= 0.2 \text{ cm} \\ L &= 304.8 \text{ cm} \end{aligned}$$

where the pressure between the packers is calculated using equation 6:

$$P_w = \frac{P_e - (H_1 + H_2)}{2} \quad \text{Eq 6}$$

$$\text{then } k_a = \frac{Q_s}{55.1399 (15^2 - P_w^2)} \text{ (for air)} \quad \text{Eq 7}$$

$$\text{and } k_n = \frac{Q_s}{58.9647 (15^2 - P_w^2)} \text{ (for nitrogen)} \quad \text{Eq 8}$$

EXAMPLE CALCULATION

An example calculation is given using data collected from a No. 3 Tunnel test conducted at a depth of 3 ft (0.91 m). The pressure decay data

is shown in Figure 3, while the tabulated pressure/time decay data is given in Appendix A.

Using equation 2:

$$q = V \frac{520}{515} \cdot \frac{(H_1 - H_2)}{76 \Delta t}$$

where,

$$V = 4427.44 \text{ cm}^3$$

$$H_1 = 20 \text{ psi}$$

$$H_2 = 3 \text{ psi}$$

$$\Delta t = 3 \text{ min}$$

$$q = \frac{4427.44 (520) (20 - 3) 5.1715}{(515) (76) (3)}$$

$$q = 1723.77 \text{ cm}^3/\text{min}$$

Using equation 4:

$$Q_s = \frac{q}{19.66} \quad \text{Eq 4}$$

$$Q_s = \frac{1723.77}{19.66}$$

$$Q_s = 87.7 \text{ ft}^3/\text{day}$$

Using equation 6:

$$P_w = 15 - \frac{H_1 + H_2}{2} \quad \text{Eq 6}$$

$$P_w = 15 - \frac{20 + 3}{2}$$

$$P_w = 3.5 \text{ psi}$$

Donkin Mine, Tunnel #3, 800 m
March 21, 1985
Depth: 3 ft
Flow #603-58SS @ 20 psi

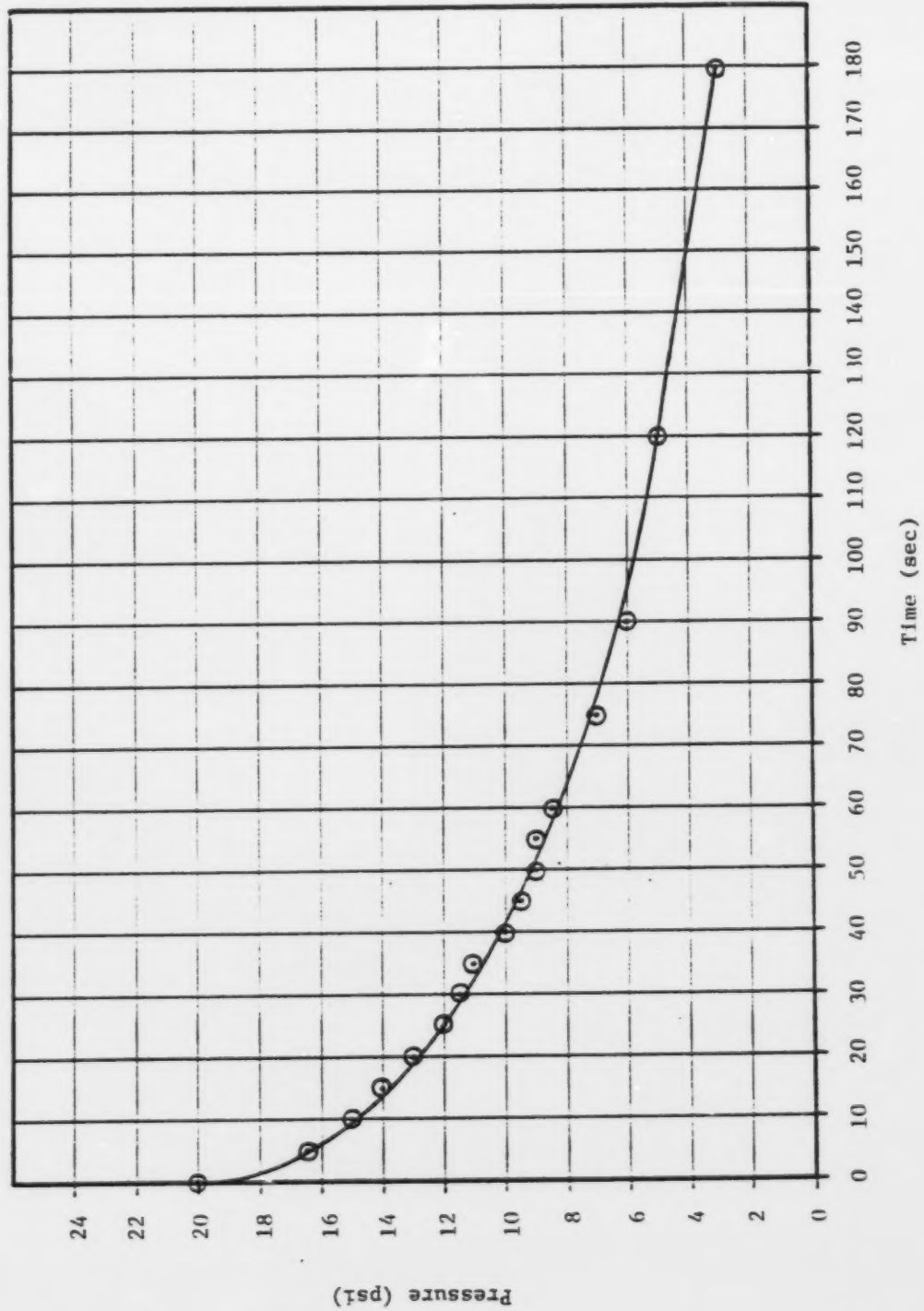


Figure 3 - Pressure decay curve, No. 3 Tunnel test section at 3 ft

Therefore using equations 7 and 8:

$$k_a = \frac{87.68}{55.14 (15^2 - 3.5^2)} \quad \text{Eq 7}$$

$$= 0.00747 \text{ darcies}$$

$$k_n = \frac{87.68}{58.96 (15^2 - 3.5^2)} \quad \text{Eq 8}$$

$$= 0.00699 \text{ darcies}$$

The permeability of the No. 3 Tunnel test section at 3 ft is therefore calculated as being:

$$k_n = 0.00699 \text{ d (6.99 md) } (6.75 \times 10^{-6} \text{ cm/sec})$$

$$k_a = 0.00747 \text{ d (7.74 md) } (7.22 \times 10^{-6} \text{ cm/sec})$$

TEST RESULTS

A summary of the field data and results for both the No. 2 Tunnel and No. 3 Tunnel test sections is given in Table 1. It should be noted that in addition to calculating the nitrogen permeability of the test section, a theoretical air permeability was also calculated.

Measureable pressure losses from the test section were only observed to a depth of 3 ft (0.91 m) in the No. 2 Tunnel and 7 ft (2.13 m) in the No. 3 Tunnel.

Tabulated pressure/time decay data for all the borehole sections tested is given in Appendix A, while the same data in graphical form is given in Appendix B.

DISCUSSION OF RESULTS

In situ gas permeability testing was undertaken to determine the extent of the zone of disturbance created by the two different excavation techniques used to drive the No. 2 (TRM) and No. 3 (drill and blast) tunnels.

Figure 4 shows nitrogen permeability plotted against the distance of the test section from the No. 2 and No. 3 Tunnel side walls. In the No. 2 Tunnel, no detectable pressure loss and hence permeability was measured beyond the test section 3 ft from the borehole collar. However, a significant increase in permeability occurred between the 2 ft (0.61 m) and 3 ft (0.91 m) test sections (1.80×10^{-5} to 8.22×10^{-4} cm/sec). This increase in permeability is probably due to the intersection of a fracture or joint within the strata.

In the No. 3 Tunnel, blast damage can be expected to induce fractures on either the micro or macro scale, in strata adjacent to the excavation surface. The closer the tunnel surface the greater the magnitude of the induced fractures. However, as the distance away from the excavation surface increases, the magnitude of the induced fracturing should decrease until the strata reverts to undisturbed conditions. Examination of the results shows a decrease in the permeability values, going away from the excavation surface, with undisturbed conditions commencing at about 7 ft (2.13 m).

CONCLUSIONS

In situ gas permeability testing can be used to assess the integrity and development of micro/macro fracturing in strata surrounding mining excavations.

Testing of the portal sandstone at the Donkin-Morien mine site, produced in situ nitrogen permeability values ranging between 8.61×10^{-7} and 8.22×10^{-4} cm/sec (0.89 to 852 md). In the No. 2 Tunnel, permeability changes were only detected to a distance of 3 ft (0.91 m) from the excavation surface, while in the No. 3 Tunnel undisturbed conditions were encountered to 7 ft (2.31 m). These results indicate that the zone of disturbed strata around the No. 3 drill and blast tunnel is three times the size of the equivalent zone surrounding the No. 2 TBM Tunnel.

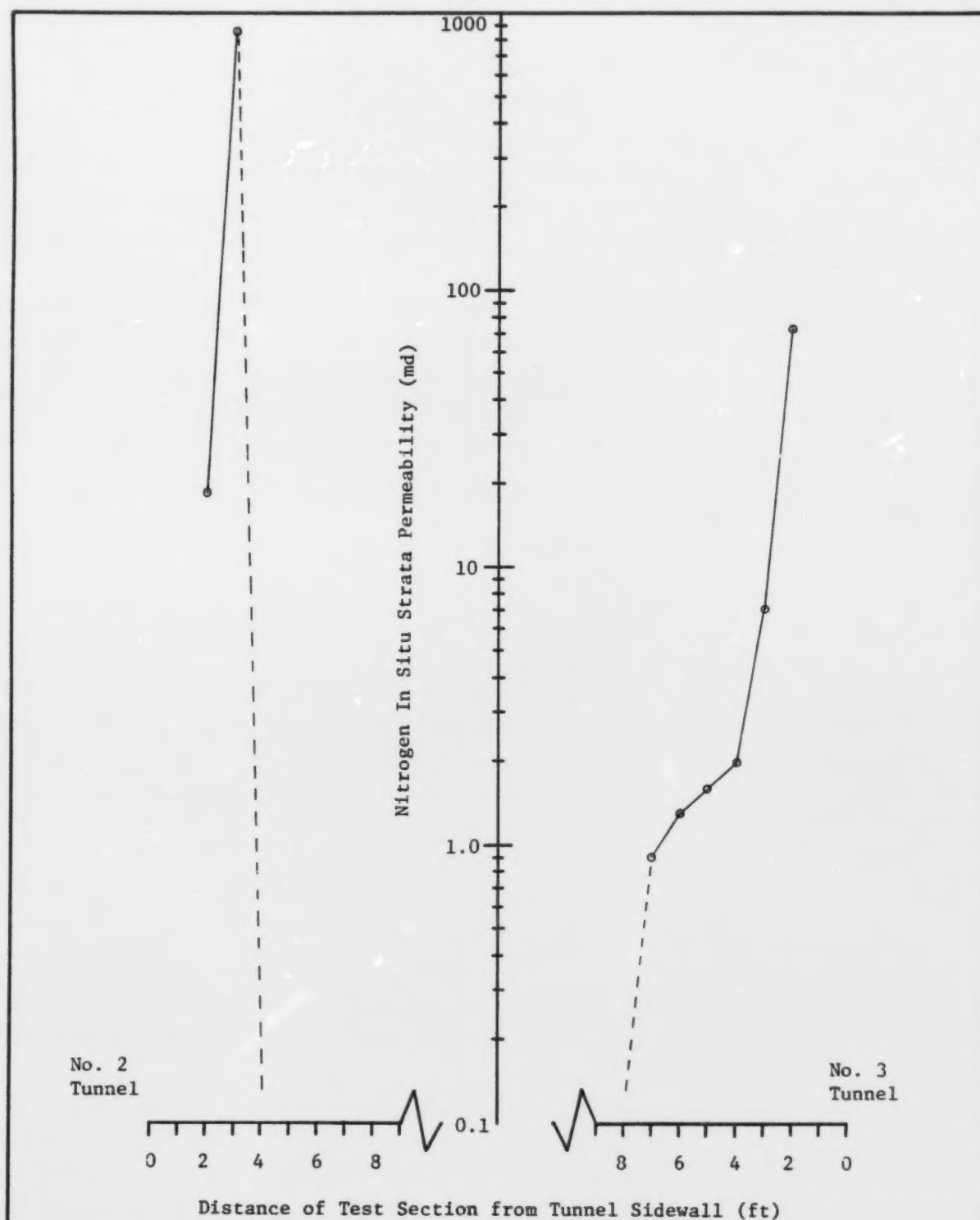


Figure 4 - Nitrogen in situ strata permeability against distance of test section from tunnel sidewall

Finally, it is concluded that in situ gas permeability testing of strata surrounding an excavation can be a useful technique in mining research and that further work should be conducted at either the Donkin-Morien mine or other mines within the Sydney Coalfield.

REFERENCES

1. CANMET 'Measurement and analysis of rock deformation and support system response in the drill and blast and bored access driveages at the Donkin-Morien Project (UP-G198).
2. Gorski, B. 'Laboratory test results of rock cores from borehole 3T804, Donkin-Morien rock support interaction contract'; Division Report MRP/MRL 85-9(INT); CANMET, Energy, Mines and Resources Canada.
3. Gallant, W.D. and Aston, T.R.C. 'Measurement of in situ strata gas pressure at No. 26 Colliery, Sydney Coalfield, N.S.'; Division Report ERP/CRL 85-10(TR); CANMET, Energy, Mines and Resources Canada.
4. Herget, G. 'In situ gas permeability in a potash mine'; Division Report MRP/MRL 81-135(TR); CANMET, Energy, Mines and Resources Canada.
5. Calhoun, J.C. Jr. 'Fundamentals of reservoir engineering'; University of Oklahoma Press; Norman; p 417; 1953.

A-14

APPENDIX A

DONKIN-MORIEN MINE NO. 2 TUNNEL - CH 804 m

In Situ Nitrogen Permeability Tests

March 19, 1985

Depth from Borehole Collar - 2 ft (0.61 m)

Time (secs)	Pressure* (psi)	Pressure** (psi)
0	14.5	15.0
5	10.5	10.0
10	9.0	9.0
15	8.0	7.5
20	7.0	6.5
25	-	5.5
30	6.0	5.0
35	-	4.5
40	5.0	4.0
45	-	3.5
50	4.0	3.0
55	-	2.5
60	3.0	2.0
90	2.0	-

* Flow #603 - 69SS @ 14.5 psi

** Flow #603 - 85SS @ 15.0 psi

Depth from Borehole Collar - 3 ft (0.91 m)

Time (secs)	Pressure* (psi)
0	23
2	0

* Flow #604 - 73SS @ 23.0 psi

DONKIN-MORIEN MINE NO. 3 TUNNEL - CH 804 m

In Situ Nitrogen Permeability Tests

March 21, 1985

Depth from Borehole Collar - 2 ft

Time (secs)	Pressure* (psi)
0	16.5
5	6.5
10	4.5
15	2.5
20	0.0
25	0.0

* Flow #604 - 47SS @ 16.5 psi

Depth from Borehole Collar - 3 ft

Time (secs)	Pressure* (psi)
0	20.0
5	16.5
10	15.0
15	14.0
20	13.0
25	12.0
30	11.5
35	11.0
40	10.0
45	9.5
50	9.0
55	9.0
60	8.5
75	7.0
90	6.0
120	5.0
180	3.0

* Flow #603 - 58SS @ 20.0 psi

DONKIN-MORIEN MINE NO. 3 TUNNEL - CH 804 m

In Situ Nitrogen Permeability Tests

March 21, 1985

Depth from Borehole Collar - 4 ft

Time (secs)	Pressure* (psi)
0	27.0
5	27.0
10	26.0
20	25.5
30	25.0
40	24.5
50	24.0
60	24.0
75	23.0
120	22.0
180	20.0
210	19.0
240	18.5
270	17.5
300	17.0
360	15.5
420	14.0
480	13.0
540	12.0
600	11.5

* Flow #603 - 76SS @ 27.0 psi

DONKIN-MORIEN MINE NO. 3 TUNNEL - CH 804 m
In Situ Nitrogen Permeability Tests
March 21, 1985

Depth from Borehole Collar - 5 ft

Time (secs)	Pressure* (psi)
0	26.5
5	25.5
10	25.0
20	25.0
30	24.0
40	24.0
50	23.5
60	23.0
90	22.0
120	21.5
180	20.0
240	19.0
300	17.5
360	16.0
420	15.0
480	14.0
540	13.0
600	12.5
660	12.0
720	11.0

* Flow #602 - 66SS @ 26.5 psi

DONKIN-MORIEN MINE NO. 3 TUNNEL - CH 804 m

In Situ Nitrogen Permeability Tests

March 21, 1985

Depth from Borehole Collar - 6 ft

Time (secs)	Pressure* (psi)
0	26.5
5	26.5
10	26.0
30	25.0
45	25.0
60	25.0
90	24.0
120	23.0
180	22.0
240	20.5
300	19.0
360	18.5
420	17.0
480	16.0
540	15.0
600	14.5
660	14.0
720	13.0
780	13.0
840	12.0

* Flow #602 - 51SS @ 26.5 psi

DONKIN-MORIEN MINE NO. 3 TUNNEL - CH 804 m

In Situ Nitrogen Permeability Tests

March 21, 1985

Depth from Borehole Collar - 7 ft

Time (secs)	Pressure* (psi)
0	26.5
15	26.0
30	25.0
45	25.0
60	24.5
90	23.5
120	23.0
150	22.0
180	21.0
210	20.0
240	19.5
270	19.0
300	18.5
360	17.0
390	16.5
420	16.0
480	15.0
540	14.0
600	13.5
660	12.5
720	12.0
780	11.0
1620	6.0

* Flow #602 - 54SS @ 26.5 psi

B-21

APPENDIX B

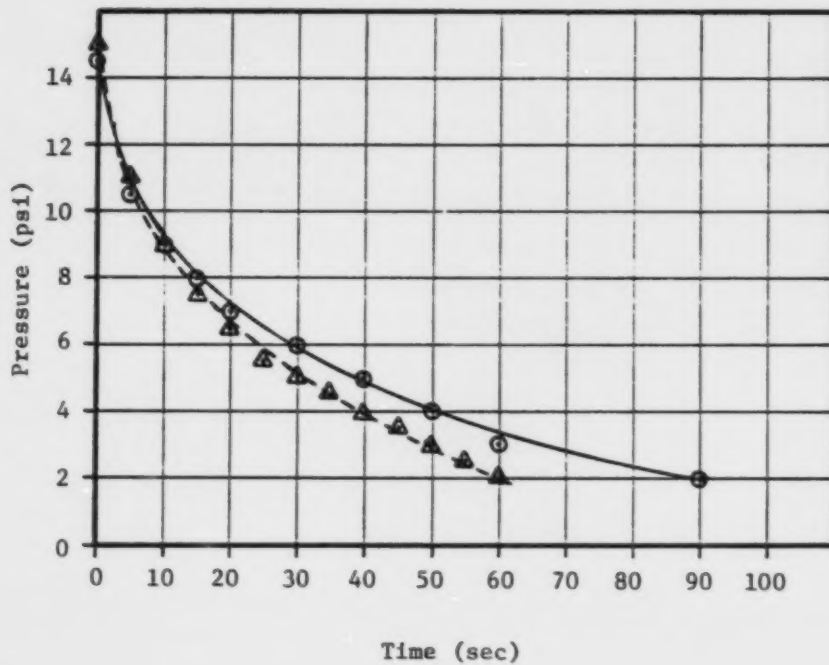
Donkin Mine, Tunnel #2, 800 m

March 19, 1985

Depth: 2 ft

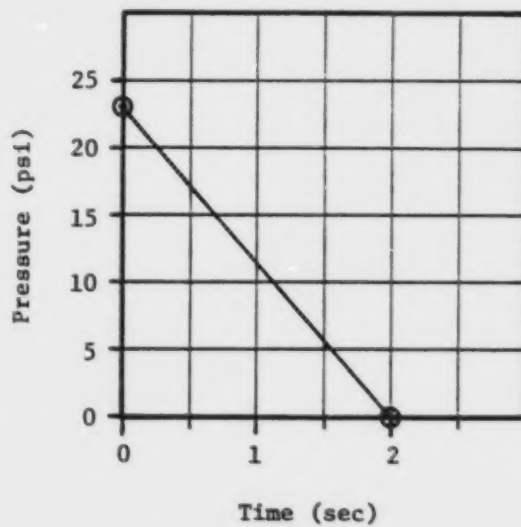
⊙ Flow #603-69SS @ 14.5 psi

△ Flow #603-85SS @ 15 psi

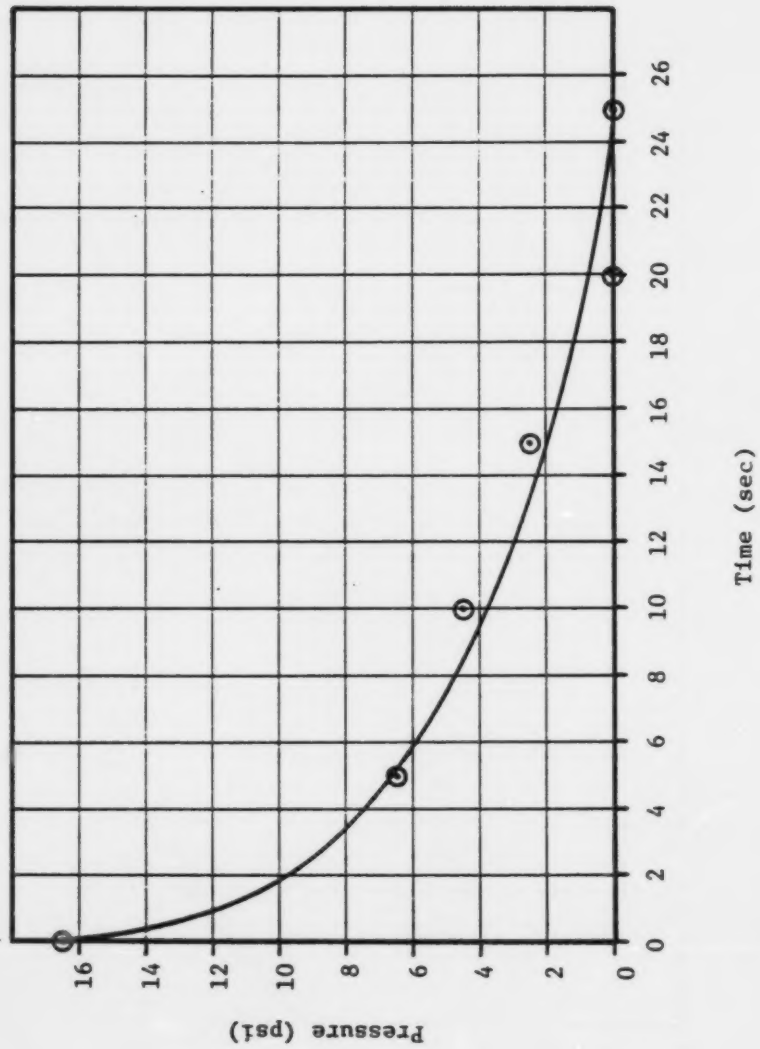


Depth: 3 ft

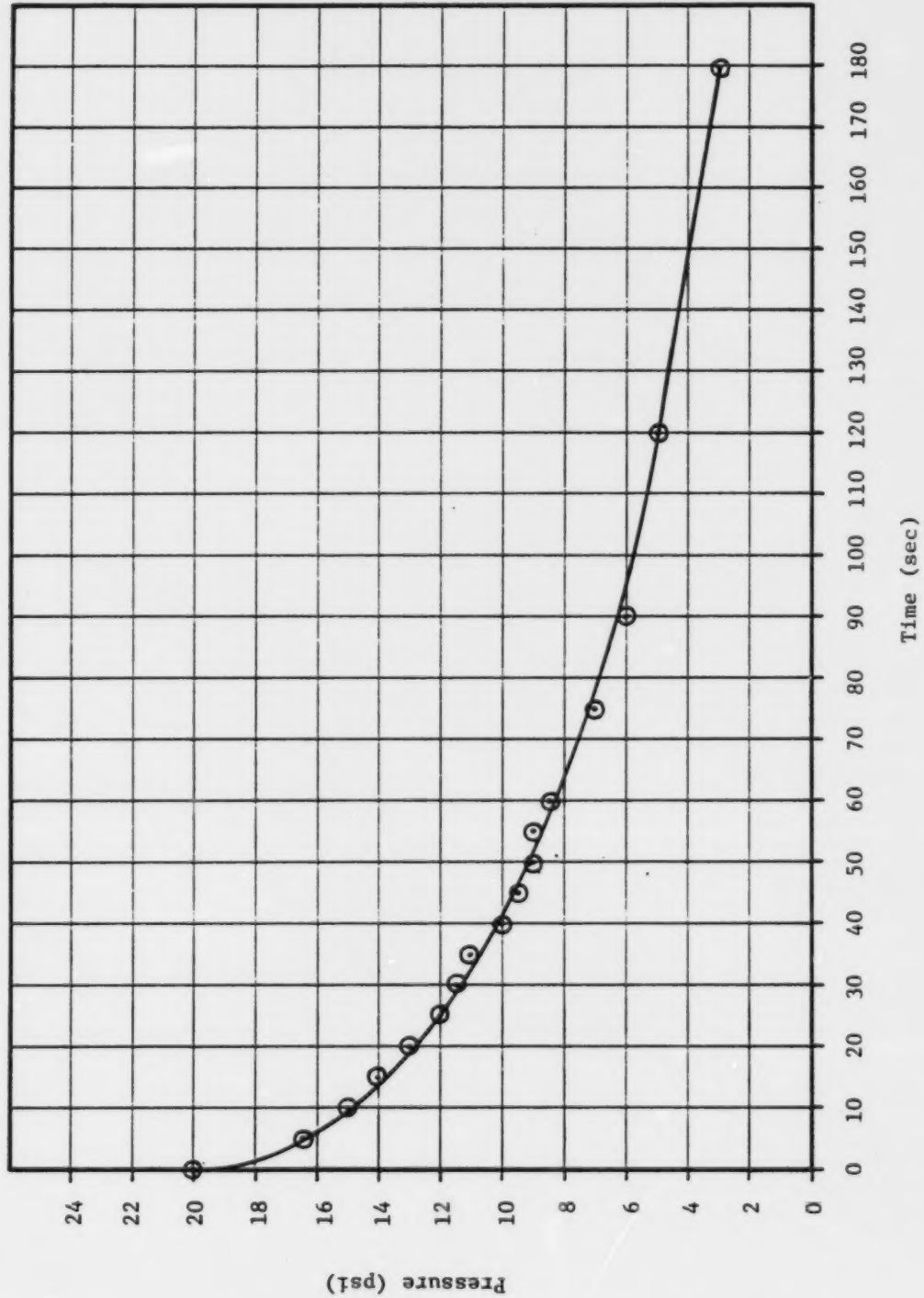
Flow #604-73SS @ 23 psi



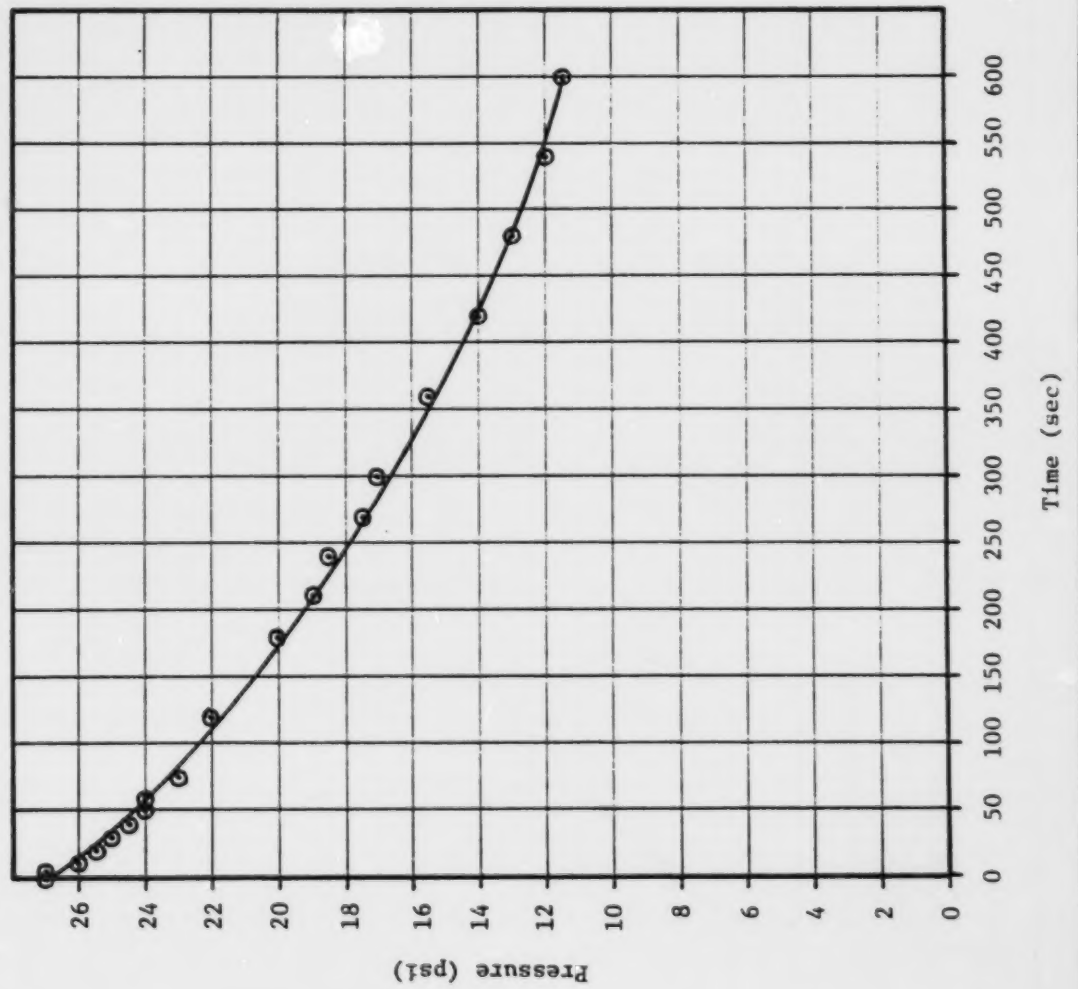
Donkin Mine, Tunnel #3, 800 m
March 21, 1985
Depth: 2 ft
Flow #604-47SS @ 16.5 psi



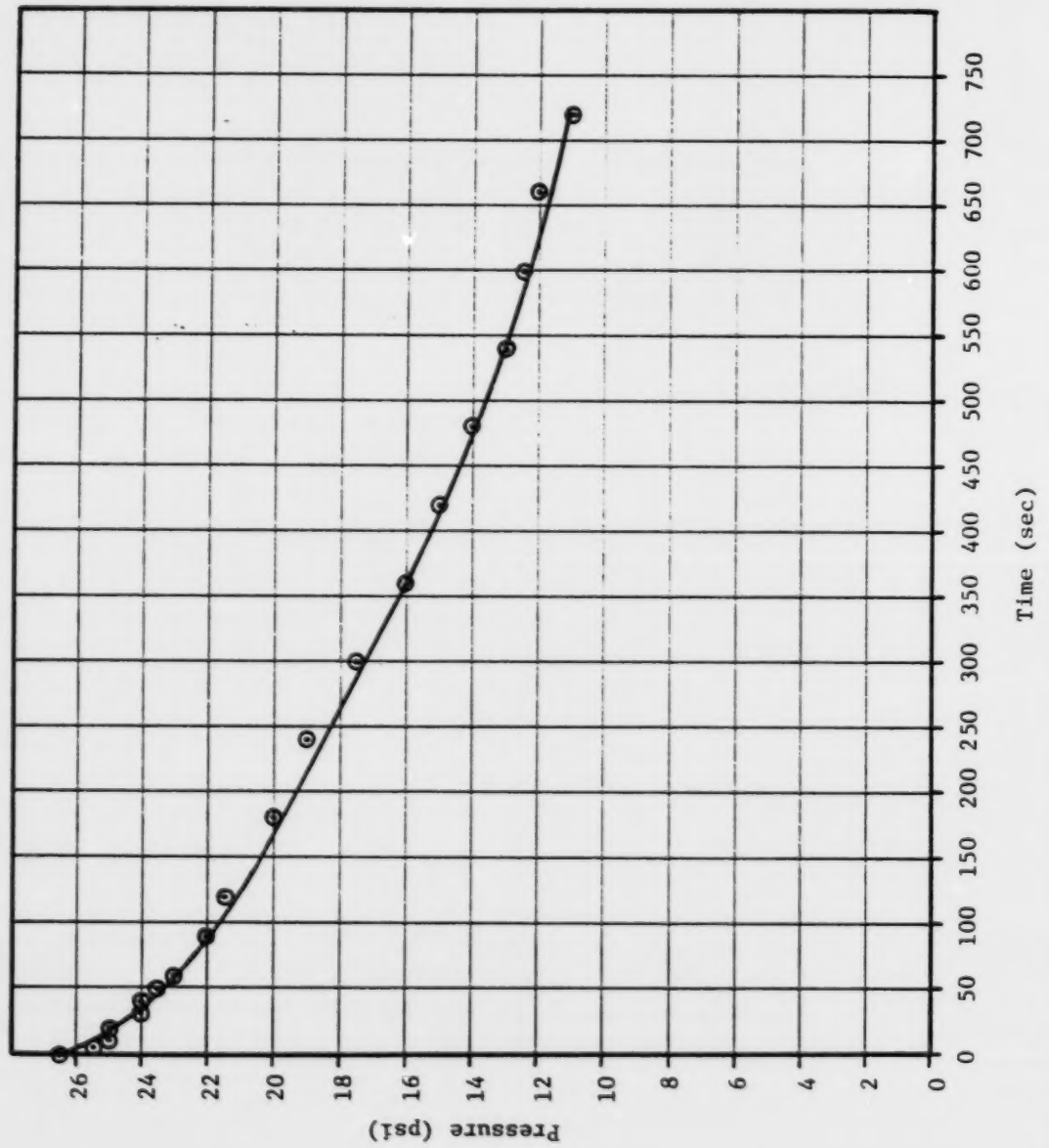
Donkin Mine, Tunnel #3, 800 m
March 21, 1985
Depth: 3 ft
Flow #603-58SS @ 20 psi



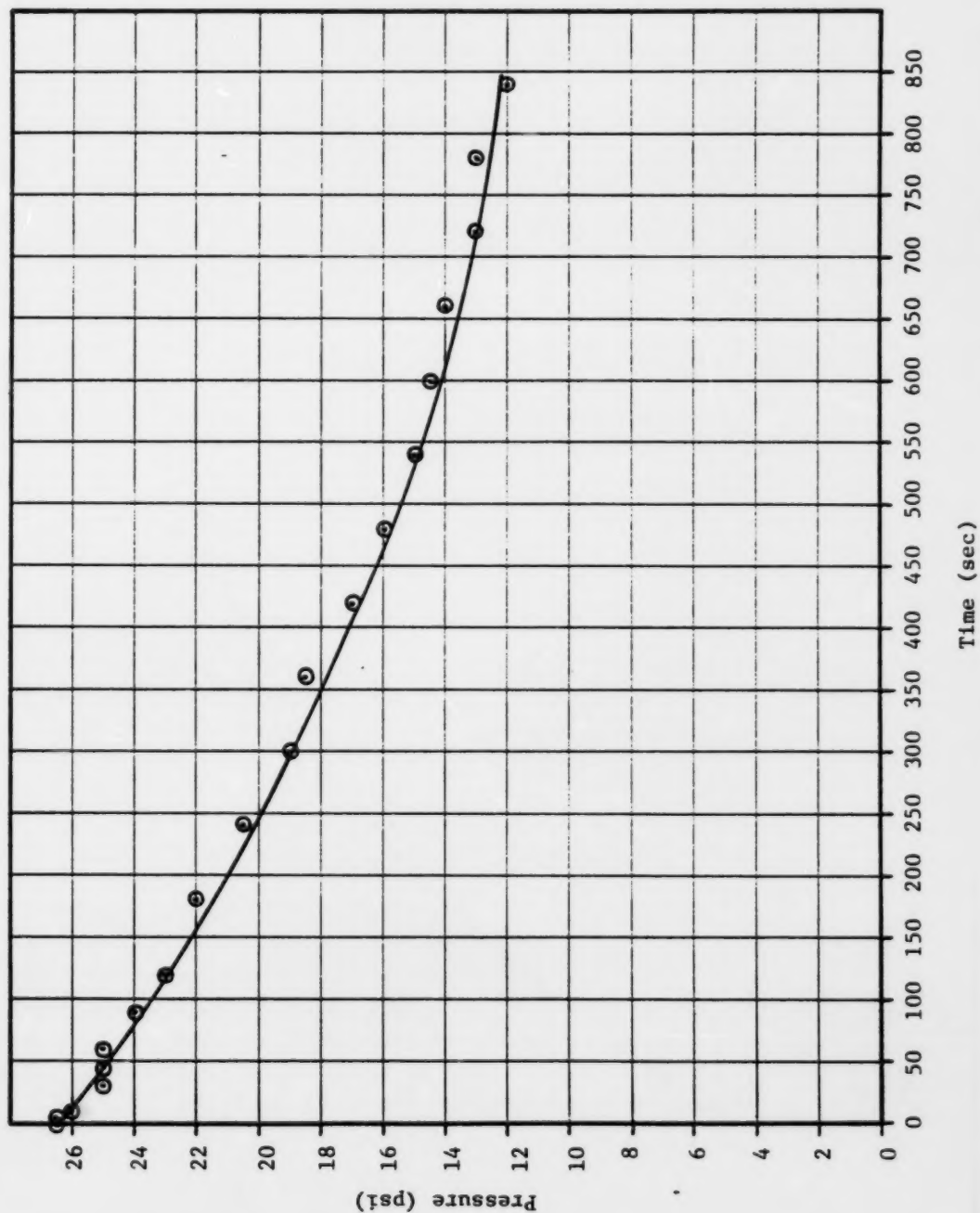
Donkin Mine, Tunnel #3, 800 m
March 21, 1985
Depth: 4 ft
Flow #603-76SS @ 27 psi



Donkin Mine, Tunnel #3, 800 m
March 21, 1985
Depth: 5 ft
Flow #602-66SS @ 26.5 psi



Donkin Mine, Tunnel #3, 800 m
March 21, 1985
Depth: 6 ft
Flow #602-51SS @ 26.5 psi



Donkin Mine, Tunnel #3, 800 m
March 21, 1985
Depth: 7 ft
Flow #602-54SS @ 26.5 psi

